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# REPRODUCTIVE DEVELOPMENT AND SEED QUALITY OF COTTON CULTIVARS AS AFFECTED BY NITROGEN FERTILIZATION

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ABSTRACT

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Because they are environmentally sensitive, a study was conducted to evaluate the growth, development and seed quality of cotton (*Gossypium hirsutum* L.) as influenced by cultivar maturity, N fertilization, and a nitrification inhibitor. Early-maturing and full-season cultivars were grown in a Bosket fine silt loam (Mollic Hapludalf) supplied with either 50 or 100 kg N/ha as anhydrous ammonia, applied either alone or with 0.56 kg/ha of nitrapyrin [2-chloro-6-(trichloromethyl)pyridine], a nitrification inhibitor. Seed cotton yields were unaffected by N fertilization at planting, but they were significantly affected by treatments applied 2 to 3 weeks earlier. Slight increases in seedling growth and a more favorable balance between reproductive and vegetative development during July and August were found in the nitrapyrin-treated plots. Both flowering and boll set were significantly increased by nitrapyrin treatment. The full-season cultivar responded favorably to increased preplant N, but the early-maturing cultivar did not. Thus, early-season cultivars may require different fertilization practices than do full-season cultivars. For each cultivar, seeds produced at 50 kg N/ha contained a significantly higher ratio of oil to protein and performed better in the field than those produced at 100 kg N/ha. The physiological interaction between N and nitrapyrin suggests the development of a production protocol to optimize seed yield with planting seed quality.

## INTRODUCTION

In much of the humid southeastern Unit States, the soils on which cotton (*Gossypium hirsutum* L.) is grown are relatively coarse and low in organic matter. The major fertilizer used on these soils is nitrogen (N), often as anhydrous ammonia. Split applications of N, with at least some of the fertilizer applied after seedling emergence, have sometimes been found

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to be desirable (Boswell, 1971). However, because of its convenience a single preplant application of N is a common practice.

Numerous studies of cotton's response to N supply have been described (Scarsbrook et al., 1959; MacKenzie and Van Schaik, 1963; Gardner and Tucker, 1967; Boswell, 1971; Ashley et al., 1974). Generally, abundant N tends to increase vegetative growth, such as plant height (MacKenzie and Van Schaik, 1963; Jackson and Tilt, 1968) but delay reproductive development and maturity (Scarsbrook et al., 1959; MacKenzie and Van Schaik, 1963; Perkins and Douglas, 1965). Leffler et al. (1977) found more protein in cotton seeds produced with abundant N. Ashley et al. (1974) found that $NH_4^+$-N increased seedling vigor, plant height, and rates of dry matter accumulation and early flowering, while $NO_3^-$-N significantly retarded the transition into flowering. Radin and Sell (1975), however, found no difference in cotton growth and development due to the form in which N was supplied. They fertilized greenhouse-grown plants with solutions containing $NO_3^-$-N and/or $NH_4^+$-N, with nitrapyrin [2-chloro-6-(trichloromethyl)pyridine] included in all solutions to inhibit nitrification.

The activity of nitrifying bacteria in the soil can be inhibited at least temporarily by products such as nitrapyrin (Goring, 1962; Hendrickson et al., 1978). With normal temperatures at Stoneville the half-life of $NH_4^+$-N applied in mid-April would be increased from 3 weeks to 6 weeks by 0.56 kg/ha of nitrapyrin (Meikle, 1978). Thus, the inhibition of nitrification provides a means to control the quantity and/or quality of N available to a cotton crop. Although Swezey and Turner (1962) reported enhanced cotton yield when nitrapyrin was used to control nitrification, few other studies with cotton have been described.

Much of the previous work has involved elevated levels of N fertilization. Since production costs continue to escalate, present interest is directed to the use of lower levels of fertilization. We initiated this study to evaluate the growth, development, yield and seed quality responses of cotton to subtle adjustments in N management.

## MATERIALS AND METHODS

Experiments were conducted in field plots near Burdette, Mississippi, during 1980 and 1981; the soil type was a Bosket fine silt loam (a fine loamy, mixed thermic Mollic Hapludalf). Factors in the experimental design included the following contrasts: cultivar maturity, early vs. full-season, N level, normal (100 kg N/ha) vs. half-normal (50 kg N/ha), time of application, 2 to 4 weeks before planting vs. within 1 week of planting; nitrapyrin [2-chloro-6-(trichloromethyl)pyridine] level, 0 vs. 0.56 kg/ha. This level of nitrapyrin is lower than that at which Geronimo et al. (1973) detected phytotoxicity on cotton seedlings. The split-split plot design incorporated cultivars and N level as the main plot, the time of application as the sub-plot, and nitrapyrin level as the sub-sub plot. Treatments were replicated eight times. Minimum plot size was four rows, 1.02 × 15 m; data were collected on the two center rows of each four-row plot. The cultivars studied were the early-maturing type 'DES 56' and the full-season type 'Deltapine 61'. Anhydrous ammonia was applied at a depth of 20 cm, with one chisel per row. The nitrapyrin was applied by gravity-flow, so the N and nitrapyrin did not mix until they were in the soil.

Growth measurements, recorded from plants in the middle half of the two center rows, included plant heights and, during the flowering period, weekly counts of first-day flowers. Seed cotton was harvested with a spindle picker, modified to accommodate plot harvesting; two harvests were made each year. Seed cotton samples (50 bolls) were hand-collected each year when approximately 60% of the crop was mature. After ginning, seeds were delinted in concentrated sulfuric acid, neutralized with a dilute solution of sodium bicarbonate, then dried at 40°C for 24 h. Subsamples (100 seeds) were used to determine seed weights and volumes. Protein and oil concentrations were measured with a Neotec GQA31-EL, as previously described (Leffler and Williams, 1983).

Seeds were planted in field evaluations the season following production. Seedling emergence and survival were scored during the first month after planting; plant heights were measured from early squaring to at least first flower. First-day flowers were counted weekly during the reproductive period.

All data were analyzed statistically; summary statistics are reported. Differences between nitrapyrin levels were tested with the '$t$'-test. A pooled error term was calculated to indicate an LSD for cultivar and N level means.

## RESULTS AND DISCUSSION

### *Seed cotton yields*

Preliminary experiments, conducted in the same manner in 1977 and 1978, had indicated a probable differential between cultivar maturities and the timing of N treatments. Therefore, yields from the 1980 and 1981 studies were grouped into preplant and at-plant sets of data, then analyzed separately (Table 1). Analysis of the yields from the preplant treatments identified several highly significant sources of variation. Principal among these were N level, the N × cultivar interaction, nitrapyrin level, the N level × nitrapyrin interaction, and years. Conversely, among treatments applied at planting, only cultivar, years, and the cultivar × years interaction produced any significant variation in the seed cotton yield. The previous experiments of 1977 and 1978 produced an equivalent pattern (data not shown). Consequently, these experiments indicate that cotton yield response to N fertilization might be dictated by the time at which the treatments are applied, especially in the mid-South production area of the U.S.A.

TABLE 1

Analyses of variance for seed cotton yields of the cultivars Deltapine 61 and DES 56, grown with various N management practices in 1980 and 1981

| Source | df | Yield (kg/ha) with treatments applied | |
|---|---|---|---|
| | | Preplant | At-plant |
| Nitrogen (N) | 1 | 2 088 097** | 48 937 |
| Cultivar (C) | 1 | 758 009* | 4 865 115** |
| N × C | 1 | 1 212 002** | 18 451 |
| Error a | 21 | 125 275 | 152 206 |
| Nitrapyrin (S) | 1 | 1 526 339** | 21 370 |
| N × S | 1 | 780 702** | 192 329 |
| C × S | 1 | 45 563 | 176 771 |
| N × C × S | 1 | 22 909 | 1 046 |
| Error b | 28 | 57 115 | 124 013 |
| Years (Y) | 1 | 1 340 573** | 5 142 901** |
| N × Y | 1 | 713 626* | 71 711 |
| C × Y | 1 | 1 063 068* | 3 219 565** |
| N × C × Y | 1 | 196 894 | 1 220 |
| S × Y | 1 | 230 352 | 2 291 |
| N × S × Y | 1 | 933 868* | 18 451 |
| C × S × Y | 1 | 117 526 | 17 755 |
| N × C × S × Y | 1 | 337 394 | 2 050 |
| Error c | 56 | 165 701 | 180 472 |

*, ** Indicate significance at the 0.05 and 0.01 levels, respectively.

In both this and the preliminary studies, responses to N were greatest in years with mid-season dry periods, when early irrigation was required. Scarsbrook et al. (1959) reported that the water use efficiency of cotton was greater if the crops were supplied high levels of N; Doss and Scarsbrook (1969) reported enhanced recovery of applied N by irrigated cotton.

The reasons for the failure of the at-plant N treatments to affect seed cotton yields significantly are not readily obvious. These results are, however, consistent with those from the earlier preliminary experiments. Since yields were generally affected only by N treatments applied before planting, the following discussion will concentrate on those treatments.

Seed cotton yields of the full-season (Deltapine 61) and early-maturing (DES 56) cultivars, as affected by preplant applications of N, are presented in Table 2. Deltapine 61 and DES 56 contrast markedly in relative maturity. DES 56 is about 13—16 days earlier than Deltapine 61. However, in this study there was also a contrast in their response to preplant N fertilization, illustrated by the significant cultivar × N level interaction shown in Table 1.

Each cultivar produced its lowest seed cotton yield in check plots receiving 50 kg N/ha, an indication that this treatment had provided inadequate N. The highest measured yields on DES 56 were from plots receiving

50 kg N/ha plus nitrapyrin. In contrast, maximum seed cotton yields produced by Deltapine 61 were from plots treated before planting with nitrapyrin and 100 kg N/ha.

Perhaps because of its full production season, Deltapine 61 responded positively to presumed increased N availability, whether it resulted from increased N fertilization or from the inhibition of nitrification. The earlier-maturing cultivar DES 56 did not positively respond to added N. Among treatments applied one or more weeks before planting, in both this and the preliminary studies, the yield responses of Deltapine 61 to nitrapyrin and N level were 172% and 388%, respectively, of those of the early-maturing cultivars.

TABLE 2

Seed cotton yields, as affected by production environment, cultivar and preplant-applied N fertilization

| Cultivar | N level (kg/ha) | Yield ($g/m^2$) with N system | |
|---|---|---|---|
| | | Control | Nitrapyrin[a] |
| DES 56 | 50 | 264 | 294** |
| | 100 | 281 | 288 |
| Deltapine 61 | 50 | 255 | 299** |
| | 100 | 313 | 328* |
| Pooled LSD (0.05) for comparing any N and C means | | 22 | |

*, ** Indicate significant difference from the control, at the 0.05 and 0.01 levels, respectively (*t*-test).

Yields of the early-maturing cultivars were increased when nitrapyrin was present at 50 kg N/ha, but were not significantly further increased by N per se. This suggests that these cultivars may be quite sensitive to early-season chemical and/or biological differences in the seedbed. The ultimate yield of a relatively determinate cotton might be presumed to be more affected by early-season growth than that of a more indeterminate type.

*Developmental indicators of response*

Except for significantly increased seedling survival in nitrapyrin-treated plots (data not shown), early-season measurements indicated few differences among the treatments. At early squaring (floral initiation), plant heights were unaffected by the level of N, but they were significantly increased in plots treated with nitrapyrin. This increase, though significant, was quite small (from 3 to 5%).

Transition from vegetative to reproductive development, measured by flower counts, responded somewhat more to the N environments. Flowering intensity was increased by nitrapyrin treatment; this is illustrated cumulatively, by week of flowering, in Fig. 1. This increase occurred in both years, even though there were marked differences in flowering levels in 1980 and 1981. Cumulative flower counts differed significantly between nitrapyrin treatments after the second week of flowering each year. Consistent with previous reports (Scarsbrook et al., 1959; MacKenzie and Van Schaik, 1963; Harris and Smith, 1980), transition into full reproductive development was slightly delayed by the higher level of N. However, the principal effect of either reducing the N level or adding nitrapyrin was on the total number of flowers that developed, not on their relative distributions.

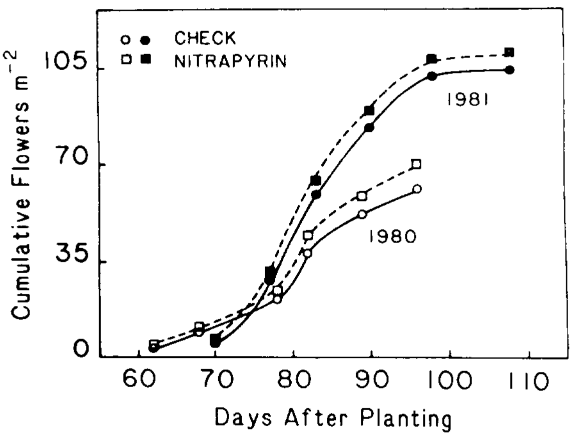


Fig. 1. Development of flowering in 1980 and 1981, as affected by the preplant incorporation of nitrapyrin. Data points represent the mean of all treatments within a nitrapyrin level. Within each year, flowering differences due to nitrapyrin level were significant after the second week.

TABLE 3

Number of harvested bolls, as affected by production environment, cultivar and preplant-applied N fertilization

| Cultivar | N level (kg/ha) | Bolls/$m^2$ with N system | |
|---|---|---|---|
| | | Control | Nitrapyrin |
| DES 56 | 50 | 58.7 | 65.9** |
| | 100 | 61.0 | 59.9 |
| Deltapine 61 | 50 | 51.4 | 57.4** |
| | 100 | 57.8 | 61.5** |
| Pooled LSD (0.05) for comparing any N and C means | | 4.2 | |

** Indicates significant difference from the control, at the 0.01 level (*t*-test).

The number of harvested bolls was estimated and reflected the increased flowering in nitrapyrin-treated plots (Table 3). Most of the yield differential shown in Table 2 was attributable to the number of harvested bolls, indicating that the enhanced flowering intensities successfully produced additional fruit. Significantly more bolls were harvested from nitrapyrin-treated plots, except those in which DES 56 was grown at the high level of N (the same plots that showed no yield increase). Correlations between the number of harvested bolls and seed cotton yields were 0.85** in 1980 and 0.79** in 1981; combined over years, this correlation was 0.83**.

An agronomic character of regular importance in the Mid-South is harvesting earliness; in this study, differences in total seed cotton yield largely resulted from differences in the first-harvest yields. Of the overall yield increases from N in 1980 and 1981, 64% and 67%, respectively, was accounted for by the increase in first-harvest yield. In comparisons of the nitrapyrin treatments, 99% and 89% of the total yield increase in 1980 and 1981, respectively, was attributable to the difference in first-harvest seed cotton yield.

*Seed quality*

In the preliminary studies of 1977 and 1978, seeds produced at 100 kg N/ha contained more protein than those produced at 50 kg N/ha. When evaluated in the field the season following production, increased rates of early seedling growth were associated with seeds produced at 50 kg N/ha, although there were only minimal differences for seedling emergence and survival. In 1980, however, no measure of seed quality (either compositional or biological) was associated with production N factors, indicating that all growth differentials in that heat- and moisture-stressed season were expressed in boll numbers and yield, not in seed quality parameters.

In the 1981 production season, the previously-observed pattern of compositional differences was again detected (Table 4). In the field evaluations

TABLE 4

Composition of cotton seeds produced under different levels of N fertilization

| Cultivar | N level (kg/ha) | Composition of seeds | | |
|---|---|---|---|---|
| | | Oil (mg/seed) | Protein (mg/seed) | O : P |
| DES 56 | 50 | 25.8 | 24.7 | 1.05 |
| | 100 | 25.6 | 27.6** | 0.93** |
| DPL 61 | 50 | 23.7 | 23.9 | 1.00 |
| | 100 | 23.1 | 26.2** | 0.88** |

** Indicates significant difference from the value for 50 kg N/ha at the 0.01 level.

of these seeds, emergence of seeds produced at 50 kg N/ha was slightly better early and survival was significantly better 5 weeks after planting. Similarly, at early squaring, these same seeds had produced significantly taller seedlings. By early flowering, however, this pattern was reversed. The highly significant growth differential indicates that plants from seeds produced at 100 kg N/ha invested more growth in vegetative than in reproductive structures during the critical squaring period.

The transition into flowering was also significantly affected by the level of N that had been provided to the seed production plots (Fig. 2). Highest flower counts, through the first 3 weeks of flowering, were in plots planted to seeds from the 50 kg N/ha plots. Plants from the 100 kg N/ha seeds flowered later, and produced more flowers only during the fourth and fifth weeks of flowering, when the flowering of all plots was declining because of a developing moisture stress. Differences between production N levels for flowering intensity during the next generation were significant at each week. The flowering advantage of the low-N seeds during the first 3 weeks further indicates that the slower rate of plant height increase during squaring may well have been associated with a greater rate of floral development.

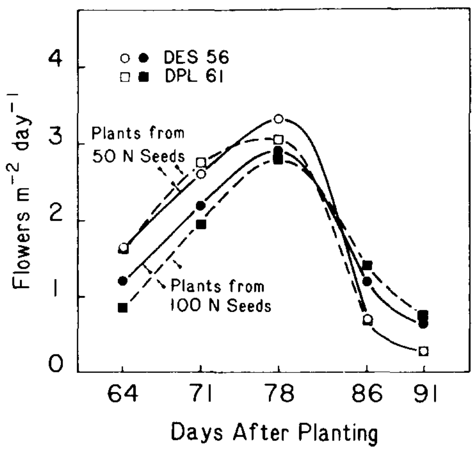


Fig. 2. Flowering of DES 56 and Deltapine 61 cottons as affected by the level of N supplied to the seed production plots.

Leffler and Williams (1983) reported that the balance between the oil and protein contents of cotton seeds reflected their ability to support seedling growth. Seeds from the low-N plots of 1981 had a significantly higher oil : protein ratio than did those from the high-N plots. This oil : protein ratio was correlated with the following seedling development measurements: (1) mid-June plant height, $r$ = 0.60*; (2) early-July plant height, $r$ = -0.65**; (3) vegetative growth during squaring, $r$ = - 0.83**; and (4) flowering distribution. Correlations between the oil : protein ratio and flowering intensity during the 5 weeks of counting were 0.69**, 0.55*, 0.69**, -0.73**, and -0.80**, respectively. These data indicate that the oil : protein ratio, suggested by Leffler and Williams (1983), may also be related to seedling performance originating in the production of a seed crop.

*General conclusions*

Taken collectively, our data illustrate subtle physiological manifestations of cotton's responses to N management. Although early-season measurements of plant height showed little response to the N systems, mid-season reproductive development was favored over vegetative development by both the lower level of N and the early-season inhibition of nitrification. These patterns suggest that the suppression of nitrification before planting created a seedbed environment that contributed to the expression of seedling physiology that ultimately resulted in enhanced flowering and boll set. Significant differences in plant growth due to differences in seedling physiology have been described previously (Leffler and Williams, 1983).

Seed cotton yields indicated that the early-season suppression of nitrification was beneficial to the crop, independent of the N level and cultivar maturity. Radin and Sell (1975) detected no effect of N form when plants were regularly fertilized with nutrient solutions, and we found no significant effect of fertilization treatments applied at planting. Therefore, the nitrapyrin-related flowering and yield responses we measured among the preplant treatments probably originated from the resistance of $NH_4^+$-N to leaching, although as yet undefined biological effects of nitrapyrin in the root zone cannot be ruled out. Yield responses to the various N management factors were more pronounced than any response measured during crop development. A significant crop maturity $\times$ N level interaction for yield was detected, which should be important, both to N nutrition studies and to production management systems. This interaction further suggests that different N management practices may be warranted for cotton cultivars that differ measurably in maturity characteristics.

Seed quality evaluations indicated that seeds produced at half-normal levels of N had a higher oil : protein ratio and performed better in the field. Without nitrapyrin, 50 kg N/ha was inadequate to produce maximum yields but 100 kg N/ha produced seeds with a lower oil : protein ratio. The combined effects of N and nitrapyrin appear to offer promise to seed producers that seed yield and seed quality can be optimized. We found that seed yields produced with nitrapyrin and 50 kg N/ha were quantitatively equivalent but qualitatively superior to those produced at 100 kg N/ha.

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